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Development of plasma-activated coconut coir biochar for the efficient removal of rhodamine B, Cu(II), nitrate and ammonium ions from aqueous media

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Access to safe drinking water is a fundamental human right. Developing green, sustainable materials for environmental remediation, particularly water purification, has gained significant momentum in recent years. Carbon-based materials have garnered considerable attention due to their highly tunable surface chemistry. However, conventional methods for synthesizing carbon materials often require high energy input, extensive chemical and solvent consumption, and significantly contribute to the carbon footprint. In this study, we replaced the conventional chemical activation method for carbon surfaces with a non-sophisticated approach using the fourth state of matter. Low-temperature pyrolyzed coconut coir biochar (BC), produced at 500°C, was functionalized using atmospheric air plasma treatment (AAPT) to produce plasma-functionalized biochar (PFBC). Plasma treatment introduced functional groups such as amines, carbonyls, and epoxies, as confirmed by Fourier transform infrared spectroscopy, enhancing the material's adsorption capabilities. Characterization of BC revealed an ash content of (7.7 ± 0.2) % and a moisture content of (9.9 ± 0.5) %. The iodine numbers, which indicate microporosity (<2 nm), were (510 ± 90) mg/g for BC and (570 ± 80) mg/g for PFBC. In comparison, the methylene blue numbers, which indicate mesoporosity (2-50 nm), were (47.0 ± 0.8) mg/g for BC and (116.0 ± 0.8) mg/g for PFBC. The point of zero charge shifted from (7.1 ± 0.2) for BC to (8.1 ± 0.2) for PFBC after AAPT. Adsorption studies demonstrated significantly improved pollutant removal efficiencies with PFBC under optimized pH conditions compared to BC. Nitrate removal increased from (6.3 ± 0.4) % to (15.6 ± 0.4) % at pH 2, Rhodamine B from (11.9 ± 0.3) % to (18.6 ± 0.2) % at pH 10, and ammonium from (16.7±0.6) % to (25.3±0.7) % at pH 8, Cu^{2+} from (57.8 ± 0.6) % to (77.3 ± 0.2) % at pH 4. All measurements were performed in triplicate to ensure accuracy and reproducibility. These results demonstrate that plasma activation improves the physicochemical properties of biochar, with the potential to provide a sustainable and efficient approach for removing cationic dyes, heavy metals, and inorganic ions from contaminated water systems.

Keywords:
Plasma activation; coconut coir biochar; Rhodamine B; nitrate; ammonium ion; removal